Geophysical Work Plan

Phase I Site Characterization
Columbia Falls Aluminum Company
Columbia Falls, Montana

Spectrum Geophysics
"Revealing The Subsurface"
3505 Cadillac Ave, #O-209
Costa Mesa, California

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1.0 INTRODUCTION

A geophysical survey will be conducted at the Columbia Falls Aluminum Company aluminum reduction facility near Columbia Falls, Montana (hereinafter referred to as the Site). This survey will be conducted in order to obtain images of both subsurface features associated with the landfills and the natural geologic/hydrogeologic features which lie beneath the landfills.

The purpose of the geophysical survey will be to delineate the lateral and vertical boundaries of the landfill materials in the northeastern portion of the Site, as well as to delineate (and identify the depth to) key interfaces in the northeastern and western portions of the site. These key interfaces are the following:

- Water table
- Landfill materials/underlying natural soils
- Underlying soils/bedrock

In order to address the objectives, electrical resistivity and induced polarization (IP) methods will be used. These methods provide a 2D image of subsurface materials along an established linear transect and are discussed in Section 3.0.

2.0 EQUIPMENT

The resistivity/IP equipment used during this investigation will consist of an Advanced Geosciences SuperSting R8/IP automated resistivity system (SuperSting) with associated cabling, power and accessories, and the EarthImager® software program (Advanced Geosciences, Inc., 2010) to process the data. Shallow utility locators and/or metal detectors will be used in addition to identify the location of subsurface utilities or shallow metallic features within the area of investigation.

3.0 METHODS

3.1 DC Resistivity/IP Method

A DC resistivity/IP survey will be conducted along linear transects in an effort to identify significant contrasts in resistivity or chargeability that are associated key interfaces in the

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subsurface at the Site. In addition, these data may provide lateral delineation of landfill material in areas where the transect crosses landfill boundaries. DC resistivity and IP data provide high quality, high resolution 2D imaging of subsurface layers in areas where there is a contrast in electrical resistivity and/or chargeability across an interface. It has been demonstrated that the electrical resistivity method is sensitive to changes in grain size, chemistry and the degree of saturation of materials. Similarly, the IP method is known to be sensitive to landfill materials, contaminant plumes and clay layers in the subsurface. Taken together, 2D resistivity and IP provide very powerful indicators of the nature of subsurface materials along an established transect, and also (much like a suite of geophysical logs for a well) allow discrimination between possible types of lithology/chemistry giving rise to an observed geophysical response- for example, discrimination between clay and saline groundwater as possible sources of a low resistivity layer in the data. As such, these methods are effective for the delineation of the lateral and vertical boundaries of landfills, and vertical boundaries such as the water table and the overlying soils/bedrock interface.

The electrical resistivity and IP methods had their beginnings in the mining industry, but are now commonly used in the environmental and engineering businesses. In the electrical resistivity/IP methods a DC circuit is established in the ground via cables and electrodes, and the ground acts as the resistor to complete the circuit. There are several different arrays that can be used to collect the data; however, the most common are Wenner, Schlumberger and dipole-dipole. Electrical resistivity/IP data are typically displayed in 2D sections or profiles where they supply lateral and vertical electrical resistivity/ chargeability information about materials directly below a given established transect (much like a road cut).

3.1.1 Electrical Resistivity

The electrical resistivity of a material is a measure of the ease with which an electrical current can flow through that material. A useful property of electrical resistivity for dry sedimentary soils and rocks is that an increase in grain size generally causes an increase in resistivity (e.g. coarse-grained materials such as gravel or cobbles have higher resistivity values than finer grained materials such as fine sands and silts). Because the electrical resistivity of a material correlates well with grain size, this method can be used not only to identify lateral and vertical boundaries between different materials but also to identify the lithology of the material (e.g. sand vs. silt vs. clay). As electrical current flow through sedimentary soils and rocks is primarily electrolytic, permeable materials (such as coarse sandstones or fractured granitic rock) are less resistive (or more conductive) when saturated than when dry – which makes the electrical resistivity method useful for many groundwater applications. In addition, because ionic conduction is enhanced by the presence of dissolved salts in the pore fluid, soils and rocks saturated with saline or high-TDS groundwater will have lower levels of resistivity than soils and rocks bearing fresh water.

3.1.2 Induced Polarization

The chargeability of a material is a measure of its ability to polarize, or hold charge. IP is also known as "complex resistivity," or resistivity as a function of time (time domain IP) or frequency (spectral IP). In the time domain IP method used by the SuperSting, a known amount of current is injected into a section of ground via electrodes, the current is then turned off, and the voltage between two other electrodes some distance away is measured at specific time intervals (or gates) after current turn off during a specified integration time (typically 2 seconds). For each measurement location, the measured residual voltage at each time gate is then normalized by the primary voltage, and the result is called chargeability, with units of mV/V or milliseconds (ms) and can be plotted on a decay curve.

IP is a surface phenomenon which takes place at the interface between an electrolyte and a mineral grain. The chargeability of a material depends on the salinity of the electrolyte, grain size distribution, ion exchange properties of the interface, thickness of the electrical double layer, current pulse duration and excitation frequency. Clays and landfill materials tend to have higher chargeability than sands or granites. In the case of clay this is because clays tend to have more free ions available; in the case of landfills the landfill constituents and the chemical reactions taking place in the waste layer give rise to higher ion exchange capacity in landfill materials. Depending on the composition of landfill materials, the presence of metals, acids or ionic interactions in the landfill leachate can enhance the IP response.

3.1.3 SuperSting System

The SuperSting will be used to collect the resistivity/IP data during this project. The SuperSting is a system that allows automated acquisition of electrical resistivity and IP data. Because it is automated it is quite efficient and relatively easy to use in the field. During a resistivity survey, a known amount of current is introduced into the ground through two electrodes. This current then travels through the ground and the electrical potential is measured by 2 other electrodes some distance from the current electrodes. In the IP method, the system measures the electrical potential at several different time "gates" once the current is turned off, to provide a measure of resistivity as a function of time, or time domain IP. Ohm's Law (V=IR) is then used to calculate the apparent resistivity and apparent chargeability of the ground through which the current has traveled. During a SuperSting survey, many apparent resistivity/ chargeability measurements are made for a suite of electrode pair separations, and these apparent resistivity values are plotted on a two-dimensional diagram (location of measurement vs. depth). The result is a 2D subsurface image that contains both sounding and profiling data. The automated resistivity/IP data acquisition provided by the SuperSting allows for a tremendous amount of data to be acquired relatively quickly at very high-resolution capability. Once the data have been acquired for a given transect, they can be downloaded to a field computer and subsequently viewed, color-contoured, and interpreted for features of interest.

3.2 Utility Locators

Utility locators and shallow metal detectors will be used to delineate metallic/conductive utilities in the immediate vicinity of the established resistivity/IP transects in order to distinguish anomalies caused by utilities from those caused by features of interest.

Utility locators such as the Dynatel 500A (Dynatel) and Radiodetection 4000 (RD4000) are specifically designed to accurately locate and delineate metallic or conductive underground pipes and utilities. These locators are designed to detect the magnetic field resulting from an electric current flow on a line. During the use of a locator, a transmitter emits a radio-frequency source signal that induces a secondary electromagnetic field in nearby utilities. A receiver unit measures the signal strength of this secondary magnetic field and emits an audible response to allow the precise location and tracing of the pipe, cable, or other conductor in which the signal is induced. If the utility is accessible, the source signal can be directly connected to it, which makes the secondary field much larger and more readily measurable. Where no direct connection is possible, the Dynatel and RD 4000 can be used to inductively trace the pipe or cable. Utility locators are effective for the location of long, linear metallic objects.

The Fisher M-Scope (M-Scope) will be used to augment the investigation of metallic utilities and to locate shallow buried metallic features (such as buried vaults) at the Site. The M-Scope has a transmitter and a receiver at the ends of a short boom. The transmitter emits a radio-frequency source signal that induces a secondary magnetic field in metallic material in its immediate vicinity. The receiver measures the signal strength of this secondary magnetic field and emits an audible response, the volume and pitch of which increase in the presence of metallic material. The sensitivity of the M-Scope allows the precise identification of the lateral boundaries of a metallic object.

4.0 SCOPE OF WORK

4.1 Field Data Acquisition

Electrical resistivity and IP data will be collected along six transects at the Site. These transects vary in length from 1300 to 1800 feet and are depicted in Figure 1.

Prior to any data acquisition at the Site the geophysics crew will use a survey chain to establish the proposed transects. A concerted effort will be made to make each transect as long as possible in order to make sure that the edges of each transect fall outside of the anticipated landfill boundary, and to maximize the depth of investigation along the transect in order to detect the top of bedrock (a good rule of thumb is that the length of the resistivity/IP line is approximately five times the desired depth of investigation). It is anticipated that four transects will be established in the northeastern portion of the Site and two transects will be established in the western portion of the Site. It should be noted that the desired length and approximate location for these lines are as depicted in Figure 1; however, these lines may need to be moved and/or shortened in the field, depending on space, actual site features and vegetation restrictions. Once the trend for each transect is established, it will be marked at either 8-meter or 10-meter increments (electrode stations) for its entire length. Steel stakes will then be hammered into the ground along each transect at each electrode station, and where necessary, salt water will be added to the soil to improve the electrical contact between the soil and the electrode.

Once the stakes are established, the resistivity cable will be attached to each stake with a rubber band to form the electrical circuit. Once this is done, the system will be set to the "automatic measurement" mode, and Schlumberger and dipole-dipole resistivity and IP data will then be acquired along each line using preloaded command files, where each linear array of electrodes consists of up to 56 electrodes (depending on space restrictions). Two readings will be taken for every measurement to allow a check on repeatability and noise in the data.

Once the data are acquired, the data will be downloaded to a field computer, reviewed for quality and saved in a raw data file. If present or necessary, utilities within 30 feet of each established transect will be delineated using utility locators and marked on the ground so that resistivity data anomalies from utilities can be identified in the data collected. During this process a detailed resistivity/IP cultural feature transect map will be made for each transect established, so that the locations and orientations of utilities and cultural features that could give rise to noise in the data are properly documented. Relative elevations along each resistivity transect will be obtained by the geophysics crew using a stadia rod and eye level. If desired, these relative elevations can then be tied to surveyed elevations of the nearest bench mark.

4.2 Data Processing

The raw resistivity/IP data file for each transect will be entered into the software program EarthImager® (AGI, 2010). This program reads the data file, which contains information such as electrode spacing, length of transect, number of repeat measurements per electrode, and type of resistivity/IP array. After the data are read into EarthImager® they are reviewed for indication of erroneous or noisy data using several different interactive color graphic data displays (further described in Section 5.2). Appropriate removal of noisy data is then carried out, and a final edited data file is created and saved; this file contains both the final measured apparent resistivity pseudosection and the final measured apparent chargeability pseudosection. To carry out the inversion, this final edited data file is then read into EarthImager® along with topography information, and the data are then sorted into finite element blocks, where each block is assigned an initial resistivity/chargeability value.

A forward modeling algorithm that uses a non-linear least squares optimization technique is used to first calculate synthetic apparent resistivity/apparent chargeability values that would be measured with the given array type for the starting model. The data are then jointly inverted using a non-linear inversion routine for resistivity and a linear inversion routine for the IP chargeability data, where the *synthetic calculated* apparent resistivity/apparent chargeability values are then compared with the *actual measured* apparent resistivity/apparent chargeability values, and the difference between the two used to improve the model to produce a resistivity/chargeability model that has a lower root-mean-square (RMS) error fit to the measured sections. The program advances through a series of iterations to improve the model until an acceptable error level is reached (usually 10% or less) or the inversion converges.

For each transect, the final product of the processing is two color-contoured model sections – one of resistivity and one of chargeability. The final fitting error between the *synthetic calculated* apparent resistivity/apparent chargeability pseudosection and the *actual measured* apparent resistivity/apparent chargeability pseudosection is represented as the RMS (root mean square) in percent. It is from these model sections that interpretations of the lateral and vertical boundaries of landfill materials, as well as key subsurface interfaces, will be made.

It should be noted that the resolution of the resistivity/IP method decreases with increasing depth. Therefore, the finite element mesh becomes coarser with depth, providing lower resolution and a more generalized model. This tends to produce broadening and flattening along the lower boundary. The highest resolution and most accurate depth conversion data are provided in the upper 30% of the model section, where the overall resolution is approximately one-half the unit electrode separation.

5.0 DATA QA/QC

Several different measures will be taken to ensure that quality resistivity/IP data are collected. In addition, several measures will be used in the data processing phase to ensure that the final raw data set used in the geophysical inversion process is free of erroneous or noisy data points.

5.1 Daily Field Testing

Each day once the resistivity/IP equipment has been deployed on a given transect, the electrical circuit has been established, and before any resistivity/IP data are acquired, a few manufacturer-recommended tests will be conducted to ensure that the equipment is working properly. First, the SuperSting will be turned on and the battery voltage verified: since the system will be run in "boost" mode (two deep cycle batteries powering the system) in order to collect both resistivity and IP data, the battery reading on the display of the SuperSting console will be checked and verified to be at least 12.0 Volts or higher. If the battery reading falls below 12.0 Volts, the main battery will be replaced with a fresh battery, and the procedure repeated. Once the battery voltage has been verified, the manufacturer recommended tests will be run.

A relay test will be run next to verify that the internal electrical communications between the cable, the passive switch box and the SuperSting console are working properly. During this test the A and B relays are checked between individual pairs of electrodes, beginning with the first two electrodes and stepping through until the last pair of electrodes is tested. Once the relay test has been passed, the contact resistance test is run.

The contact resistance test is run on the electrodes to ensure that enough current is traveling through the ground to obtain accurate measurement results of the subsurface materials. During this test, a small amount of known current is sent down the cable and the system steps down the line of electrodes and reads the voltage (and thereby the resistance) between pairs of electrodes (one pair at a time) and displays the resistance value in real time on the console. If the resistance is above 1.5 k-Ohm for a particular pair of electrodes, the SuperSting operator then stops the test and the electrode connection is checked and improved (usually by hammering the stake deeper into the ground or re-watering the electrode), and the procedure is repeated, until all pairs of electrodes on the line have passed the requirement of contact resistance of 1.5k-Ohm or below.

5.2 ***Data Processing QA/QC***

Data processing QA/QC involves the interactive viewing of data points after they have been collected, to allow the removal of erroneous data points prior to the inversion of the data. As previously discussed, the data file saved for each resistivity/IP transect will be entered into the software program EarthImager® (AGI, 2010). Once the data are read into EarthImager® each raw data set is reviewed for indication of erroneous or noisy data using interactive displays of several different measurement parameters, depending on the type of data. The resistivity data are reviewed for measured voltage, apparent resistivity, injected current, repeatability and geometric factor. The IP data are reviewed for measured voltage, apparent chargeability, voltage decay, and correlation coefficient. The EarthImager® program has several automated methods to remove noisy data, including user-specified parameter thresholds in the "Criteria for Noisy Data Removal" menu in the "Initial Settings" page for resistivity or chargeability, as well as user-specified data misfit thresholds where data misfit scatter plots and histograms can be used to remove erroneous data. Once these parameters for data removal are established, the program removes the noisy data and saves the resultant file for further processing. This process can then be refined and repeated until an acceptable noise level in the data is obtained. During this noise removal process, care will be taken to review the detailed cultural feature transect maps made for each transect so that well-established patterns in the data caused by utilities and similar features can be removed from the final measured data pseudosections.